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## Thermal Aging Studies of Encapsulated Motorette Insulation Systems



MARINE ENGINEERING LABORATORY

TEST AND EVALUATION REPORT



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By
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## ABSTRACT

Thermal aging studies were conducted on four encapsulated insulation systems on motorettes to establish their thermal ratings. Encapsulation of Class A and B insulation systems resulted in upgrading the Class A system from 105° to 138° C and the Class B system from 130° to 150° C. It is recommended that the encapsulated insulation systems studied be rated thermally Class B. Work is under way on determining how long encapsulated systems will remain sealed from a hostile environment.

## ADMINISTRATIVE INFORMATION

This work is authorized under Sub-project S-F013 12 04, Task 4533, Assignment 61 113.

## TECHNICAL REFERENCES


1 - Hackney, C. B., and H. P. Walker, "Insulation Systems for Naval Shipboard Motors Intermittently Submerged," AIEE Paper 60-858 of Jun 1960

2 - Walker, H. P., and R. J. Flaherty, "Severe Environmental Conditions Uncover Weaknesses in Naval Shipboard Motors," AIEE Paper 61-219 of Mar 1961

3 - Brancato, E. L., L. Johnson, and H. P. Walker, "Functional Evaluation of Motorette Insulation Systems," Electrical Manufacturing, Mar 1959, pp. 146-153

4 - "Test Procedure for Evaluation of System of Insulation Materials for Random-Wound Electrical Machinery," AIEE No. 510, Nov 1956

5 - Lee, Dr. Henry, "Comparison of Heat-Accelerated Dielectric Strength Breakdown Performance of Five Commercial Magnet Wire, Under Various Epoxy Resin Encapsulation Conditions," Epoxylite Corp., Abstract Research Rept 56-212, 1956

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# THERMAL AGING STUDIES OF ENCAPSULATED MOTORETTE INSULATION SYSTEMS

By
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## INTRODUCTION

There has been a continuing history of failures of insulation systems in electric motors on naval vessels due to high humidity and flooding. In earlier work in this problem (1957), a contract (NObs-72314) was let with the Allis-Chalmers Manufacturing Company, Norwood, Ohio, for the development of an electric insulation system specifically intended for induction motors subjected to occasional submergence in seawater. The performance of the insulation system so developed was reported by Hackney and Walker[1] in which they outlined the various insulation systems that were studied along with those that were discarded during the development of the improved system. The performance of this new insulation system when subjected to severe environmental conditions of long-term high humidity, steam, and salt spray was reported by Walker and Flaherty.[2] It was demonstrated that an encapsulted insulation system was vastly superior to each of 15 different varnish-impregnated insulation systems in withstanding severe environmental conditions.

Numerous studies have been undertaken to determine the thermal life of electrical insulation systems employing conventional varnish impregnation. Brancato, Johnson, and Walker[3] reported on an evaluation procedure for studying the thermal life of electrical insulation systems in air, which was a modification of the method described in AIEE 510[4] (i.e., without the use of visible condensation).

The major difference between encapsulated insulation and conventional varnish-impregnated systems is the thickness of the deposited material protecting the magnet wire enamel. The encapsulant is at least an order of magnitude thicker than the

[1]Superscripts refer to similarly numbered entries in the Technical References at the beginning of this report.

varnish resulting in greater slot fill around the conductors in the slot of a motor and complete coverage of end turns with the encapsulating material. There is little information available on the thermal life to be expected with such an encapsulated system. Lee[6] reported on heat-accelerated dielectric breakdown performance of encapsulated magnet wires. However, an insulation system employs many more materials than the magnet wire enamel and an encapsulant.

In an effort to answer the question of thermal life, four encapsulated insulation systems on motorettes were fabricated and heat aged. The insulation systems on these were as follows:

1. A standard Class A (105° C)* system with the varnish replaced with an epoxy encapsulant.

2. A standard Class B (130° C) system with the varnish replaced with an epoxy encapsulant.

3. The insulation system utilized by the occasional submergence motors reported by Hackney and Walker.[1]

4. The same insulation system as (3) above, with the polyester magnetic wire replaced by an epoxy-enameled magnet wire.

The purpose of these studies was to establish:

- Thermal life of the several encapsulated insulation systems.

- Comparison of the performance of Class A and B insulation systems where the conventional varnish was replaced with an epoxy encapsulant.

- Whether the degradation products of a polyester material inside of an encapsulating envelope will have an adverse effect on the life of the polyester materials.

- Whether a longer life may be expected in an encapsulated system with epoxy versus polyester-enamel-magnet wire.

- The thermal life of the insulation system reported by Hackney and Walker.[1]

*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

## MATERIALS STUDIED

The details of the motorette systems are given in Table 1.

Table 1

Encapsulated Insulation Systems

| Component | System 43 | System 44 | System 45 | System 46 |
|---|---|---|---|---|
| Magnet Wire | Heavy Polyvinyl Formal | Heavy Polyester | Heavy Polyester | Heavy Epoxy |
| Slot Cell | 0.005-Inch Rag Paper-0.005-Inch Polyester Film | 0.003-0.005-0.003-Inch Polyester Mat-Film-Mat | 0.005-0.005-0.005-Inch Polyester Mat-Film-Mat | 0.005-0.005-0.005-Inch Polyester Mat-Film-Mat |
| Wedge | 1/16-Inch Polyester Glass Mat | 1/16-Inch Polyester Glass Mat | None | None |
| Coil Separator | 0.013-Inch Rag Paper | 0.003-0.005-0.003-Inch Polyester Mat-Film-Mat | None | None |
| Phase Strip | 0.005-Inch Rag Paper | 0.003-0.001-0.003-Inch Polyester Mat-Film-Mat | None | None |
| Sleeving | Silicone Rubber Glass | Silicone Rubber Glass | None | None |
| Lead Insulation | Silicone Rubber | Silicone Rubber | Silicone Rubber | Silicone Rubber |
| Encapsulant[1] | Flexible Heat Reactive Epoxy | Flexible Heat Reactive Epoxy | Flexible Heat Reactive Epoxy | Flexible Heat Reactive Epoxy |

[1]Motorettes, preheated to 200° F, resin preheated to 175° F. Encapsulating done under vacuum with both resin and motorette subjected to vacuum prior to pouring resin.

System 43 is a standard Class A insulation system with the oil-based phenolic-varnish impregnant replaced with an epoxy-encapsulating envelope. System 44 is a standard Class B insulation system with the varnish impregnant replaced with an epoxy-encapsulating envelope. System 45 is the insulation system employed on contract NObs-72314 except a slot cell of 0.015 inch is used instead of 0.013 inch. System 46 is identical to System 45 except the magnet wire enamel is epoxy instead of polyester.

## PROCEDURE

The thermal aging procedure used for these tests consisted of the basic procedure specified in AIEE 510[4] except that the humidity condition was modified to produce no visible condensate as described by Bancato, et al.[3] In some instances the procedures were further modified as shown in Table 2.

Table 2 - Prodecure for Thermal Aging Studies[1] of Encapsulated Motor Insulation Systems

| System | Thermal Aging Temperature °C | Vibration[2] | Humidity | Voltage Stress[3] | Additional Conditions |
|---|---|---|---|---|---|
| 43 | 140<br>150 | X | X | X | None |
| 44 | 150<br>160 | X | X | X | After thermal aging in oven, cool 1/2 hour, place in 130° C oven for 1 hour, immerse in 10° C water for 10 minutes. Submerge in 4% saltwater for 24 hours, rinse, then to humidity. |
| 44A | 150 | X | X | X | None |
| 44B | 150 | X | X | X | Thermal age for 15,218 hours then subject to cycles as given for 44. |
| 45 | 150 | X | X | X | None |
| 46 | 150 | X | X | X | None |

[1]This is similar to AIEE 510[4] as modified by degree of humidity specified.[3]

[2]Vibration level of 5 mils peak to peak, 60-hertz for 1 hour each cycle.

[3]Voltage stress level applied to 10 minutes each cycle and breakdown criteria are:

| | | |
|---|---|---|
| Turn-to-turn | - | 120 volts, 0.75 ampere |
| Phase | - | 600 volts, 0.50 ampere |
| Ground | - | 600 volts, 0.50 ampere |

The effect of thermal shock on the thermal life of the insulation system was obtained by modification of the test agenda for System 44 as shown in Table 2.

It was found necessary to modify the thermal aging procedure by eliminating the accelerated aging temperatures above 160° C for these systems. When temperatures above 160° C were used, thermal expansion of the encapsulating material in the slot area cracked the envelope, destroying its integrity.

## RESULTS

The results of the thermal aging studies conducted appear in Table 3, an examination of which points up the findings as follows:

- Extrapolating the results of System 43 at 140° C and 150° C to the standard life of 40,000 hours[3] yields 138° C as the temperature rating.

- System 44A was aged at 150° C. The thermal life was 45,505 hours. This is 5,505 above the nominal 40,000-hour life[3] used for thermal rating. Therefore, System 44A may be given a conservative rating of slightly more than 150° C.

- System 45, which is the one developed under NObs-72314, has 48,800 hours and the epoxy wire enamel, System 46, has a life of 38,825 hours.

- Polyvinyl formal magnet wire enamel has a thermal rating of 105° C at 40,000 hours.[3] When used in System 43, the average turn-to-turn life at 140° C was found to be 40,020 hours. The thermal rating of the magnet wire enamel was upgraded for a thermal life at 150° C of 46,575 hours. This is above the standard 40,000-hour[3] figure by 6,575 hours. Therefore, its conservative rating would be slightly more than 150° C.

- The magnet wire enamel used in System 45 had a thermal rating of 145° C at 40,000 hours when used with a polyester varnish. When the magnet wire enamel was used in the encapsulated system, the thermal rating rose to more than 150° C.

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Table 3

Results of Thermal Aging Studies

| System | Aging Temperature °C | First Failure hours[1] | Average Turn-to-Turn hours | Average Phase hours | Average Ground hours | Remarks |
|---|---|---|---|---|---|---|
| 43 | 140 | 38,253.1 | 40,020.5 (18 of 20 failures) | 39,089.6 (9 of 10 failures) | 39,571.6 (9 of 10 failures) | First failures were primarily turn-to-turn. |
| 43 | 150 | 16,712.4 | 18,679.8 | 24,376.9 | 40,841.0 (7 of 10 failures) | First failures were primarily turn-to-turn. |
| 44 | 150 | 4,374.0 | 5,401.2 | 5,657.2 | 4,374.0 | First failures both turn-to-turn and ground type. |
| 44 | 160 | 3,326.4 | 5,104.8 | 5,342.4 | 3,326.4 | First failures primarily ground type. |
| 44A | 150 | 45,505.0 | 47,869.9 (7 of 10 failures) | >51,807.0 | 46,858.2 | First failures primarily turn-to-turn. |
| 44B | 150 | 15,218.0 | 15,752.6 (9 of 10 failures) | 16,501.2 | 15,218.0 | First failures both ground and turn-to-turn type. |
| 45 | 150 | 46,575.8 | 48,800.1 (17 of 20 failures) | 47,532.8 | 49,767.0 (8 of 10 failures) | First failures equally spread between turn-to-turn and phase. |
| 46 | 150 | 34,919.5 | 38,825.6 (18 of 20 failures) | 36,673.1 | >50,181.0 (3 of 10 failures) | First failures equally spread between turn-to-turn and phase. |

[1]40,000 hours in the thermal life for rating a particular system.[3]

o Comparing the results of thermal life of Systems 44 and 44A at 150° C reveals that the thermal life, as given by 44A at 45,505 hours, was reduced in 44 to 4,374 hours as a result of the thermal shocks which System 44 received. Also the failure changed from primarly turn-to-turn type in 44A to both turn-to-turn and ground in 44.

## CONCLUSIONS

The following conclusions are drawn as a result of these studies:

- The encapsulated Class A (105° C) system achieved a thermal rating of 138° C.

- The encapsulated Class B (130° C) system achieved a thermal rating of slightly above 150° C.

- The encapsulated system developed under Navy Contract NObs-72314 achieved a thermal rating of slightly above 150° C.

There is no adverse effect of the degradation products (principally water) from polyester used in the insulation system when they are confined by the encapsulating envelope.

- A polyester magnet wire enamel gives a longer thermal life than an epoxy magnet wire enamel when used in encapsulated equipment.

- The degradation of polyvinyl formal magnet wire enamel was shown to be essentially an oxidation process; shielding the magnet wire enamel from oxygen in the air inside an encapsulating envelope increases the thermal rating above that achieved in air.

- Repeated thermal shocks degrade an insulation system by a factor of ten, with the ground insulation becoming a predominating factor in the thermal life.

## RECOMMENDATION

It is recommended that the insulation systems studied be considered to have a thermal rating of Class B.

## FUTURE WORK

The encapsulated insulation system is one form of a sealed insulation system being developed from modern plastic materials. Sealed insulation systems are becoming increasingly important in industry as operational experience shows their advantage over conventional varnish-impregnated insulation systems in severe environments.

There are no known procedures for determining how long an encapsulated unit will remain sealed from the environment. This Laboratory is actively participating with the Institute of Electrical and Electronics Engineers Rotating Machinery Committee in developing methods of evaluating sealed insulation systems. Studies are under way at two levels of voltage stress (normal and high potentials) to determine how long these systems will remain sealed during thermal aging studies.